Deep Space Optical Communications Concept

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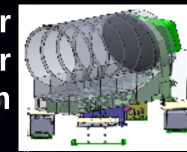
Outline

- DSOC Tech. Demo & Psyche Mission Overview
- Optical Link Conditions
- Concept of Operations
- DSOC System Desription
- Future Laser Transmitters & Ground Systems
- Summary

Deep-Space Optical Communications (DSOC) Concept

Flight Laser Transceiver (FLT) 4W, 22 cm



Psyche Spacecraft (2022)

1064 nm uplink
1.6 kb/s < 1 AU

– ***OBJECTIVES:***

Advance NASA's enhanced communication goals by:

– *Demonstrating optical communications from deep space (> 2 AU) to validate:*
  – *Link acquisition/re-acquisition and laser pointing control*
  – *High photon efficiency signaling (implement emerging CCSDS standard)*

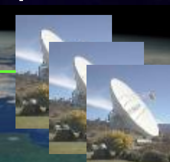
Ground Laser Transmitter (GLT)
Table Mtn., CA
1m-OCTL Telescope
(5 kW)

Ground Laser Receiver (GLR)
Palomar Mtn., CA
5m-dia. Hale Telescope

1550 nm downlink

Data-rate (Mb/s)	Distance (AU)
132	< 0.25
14	> 0.25 <1.0
2	> 1 < 2.0
0.2	> 2 <2.6

Deep Space Network (DSN)



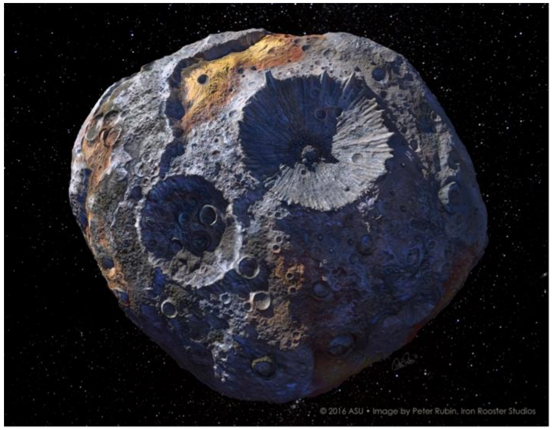
Psyche Ops Center

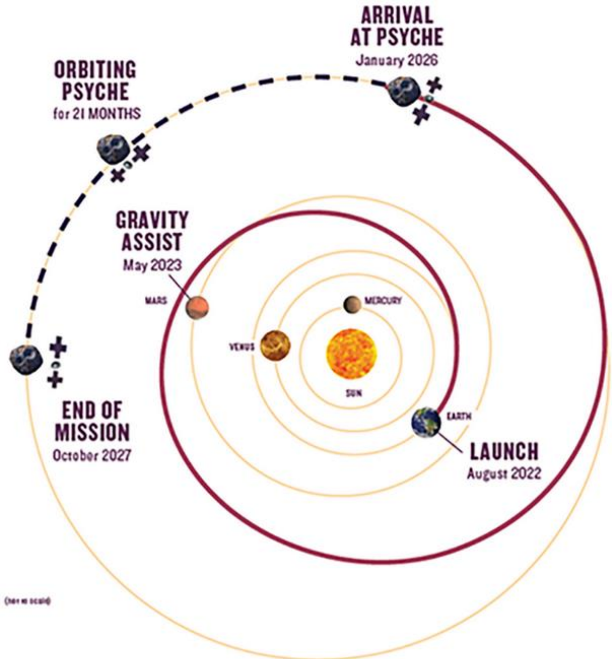
DSOC Ops Ctr.

DSOC Technology Demonstration

- **DSOC tech demo planned to be hosted by Psyche Mission**
  - Selected by NASA/Discovery Program to explore the asteroid Psyche-16
  - Primary science objective is to determine whether Psyche-16 is a core or if it is un-melted material
  - Psyche scheduled for launch in summer of 2022 with a 21-day launch window
    - Trajectory uses a Mars Gravity Assist
    - 21-day launch window around August 2022

- **DSOC tech. demo constrained by:**
  - Scheduling around Psyche mission activities and ground assets (Palomar)
  - Cloud free line of site at Palomar and OCTL simultaneously
    - Studies indicate an average of about 54% joint availability with seasonal variations
  - Limitations of Palomar telescope to operate in the daytime
  - Psyche trajectory

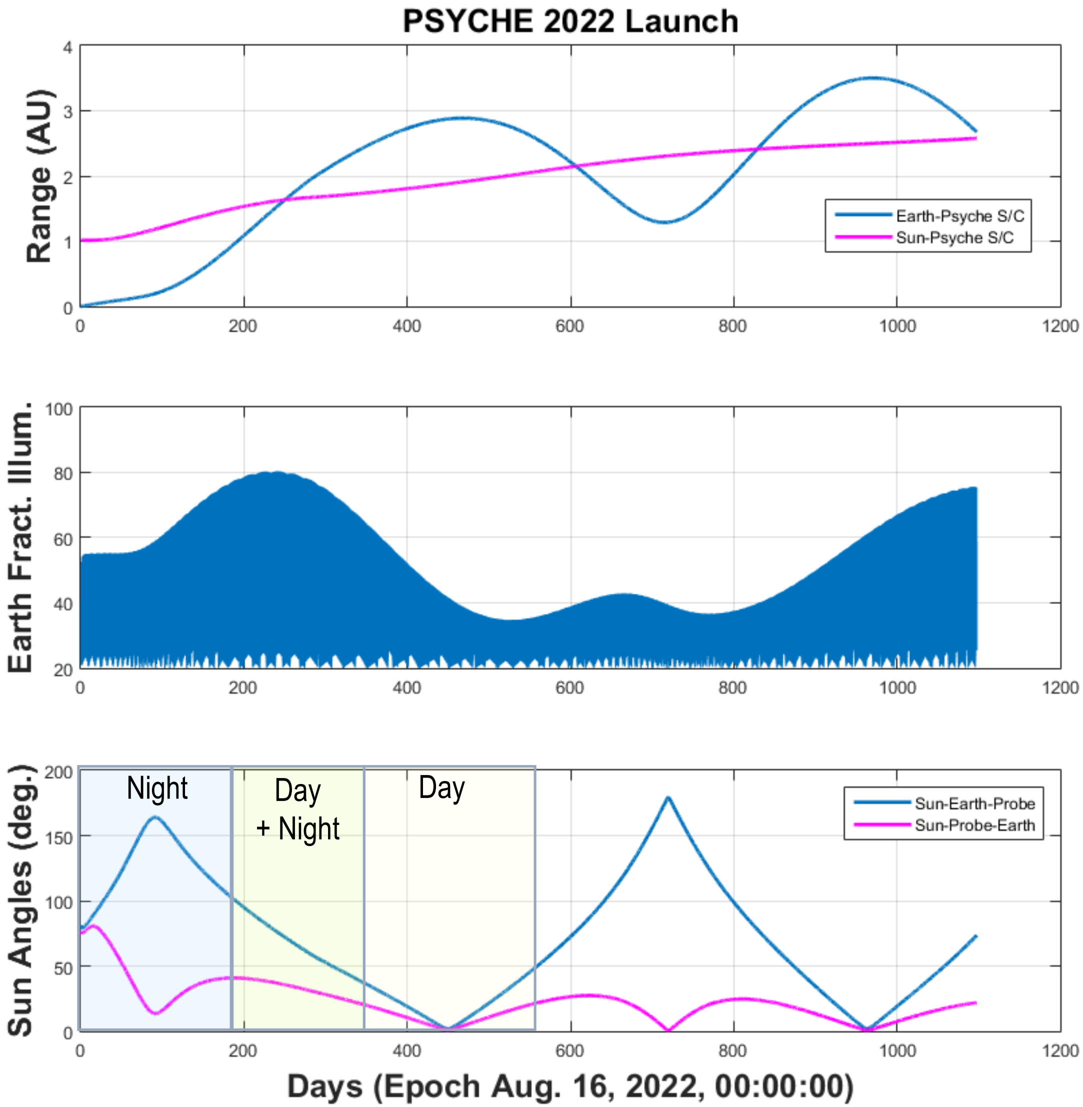




https://medium.com/the-nasa-psyche-mission-journey-to-a-metal-worldSchedule constraint

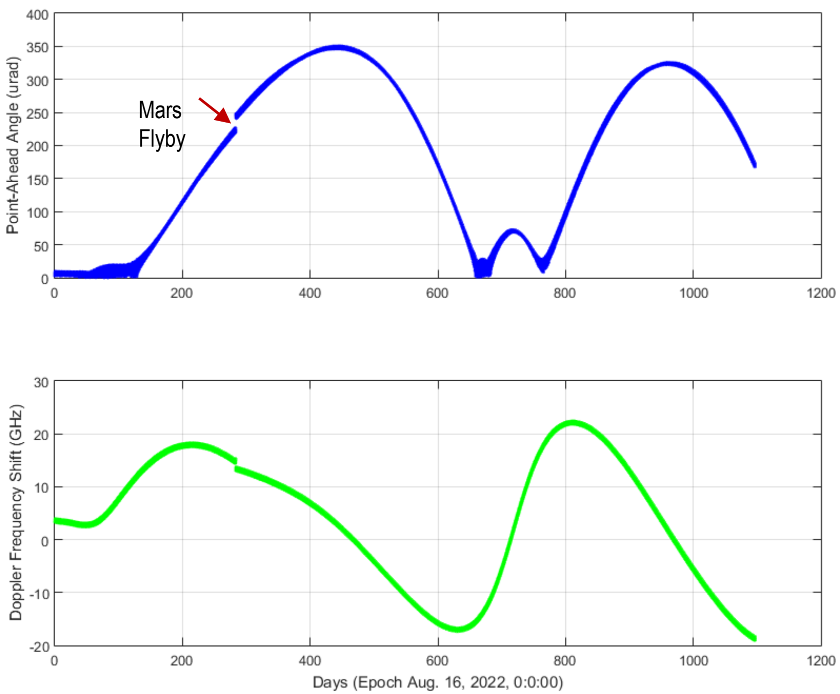
Link Conditions

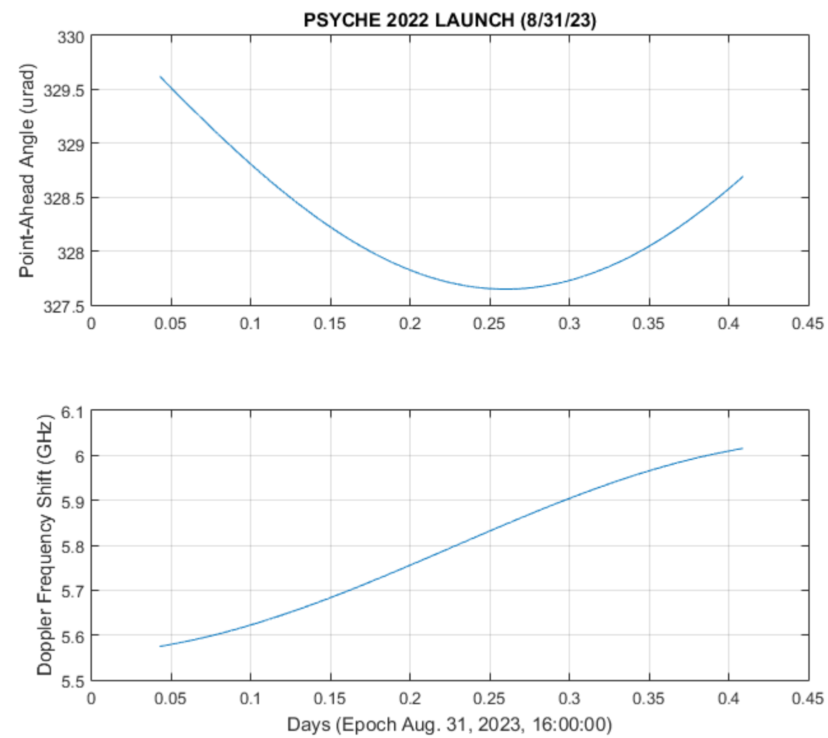
- **Psyche trajectory for observer at Palomar**:
  - Range
  - Air-mass
  - Sun angles
- **“Night” operations for nearly 250 days after launch**
- **“Day” operations restricted to TBD SEP angle**
- **Possible to meet Level 1 requirements within year from launch**
  - Likely would require two contacts per month
  - Frequency of contacts needs further analysis



Link Conditions (cont.)

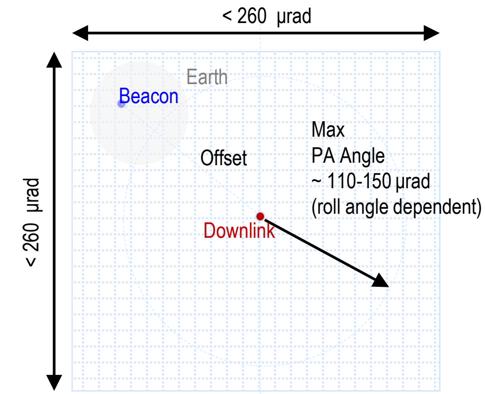
- Doppler shift/rates within optical filter widths and receiver synchronization algorithms
  - Downlink uses narrower filter and would be set based on predicts
  - Uplink filter would accommodate Doppler shifts
- Point ahead angles for downlink exceed FLT camera FOV
  - Factored into design
  - Plan to use calibrated strain gauge sensors on point-ahead mirror when PA angle exceeds FOV

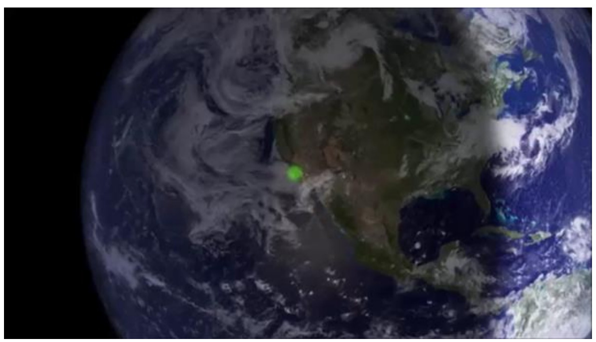


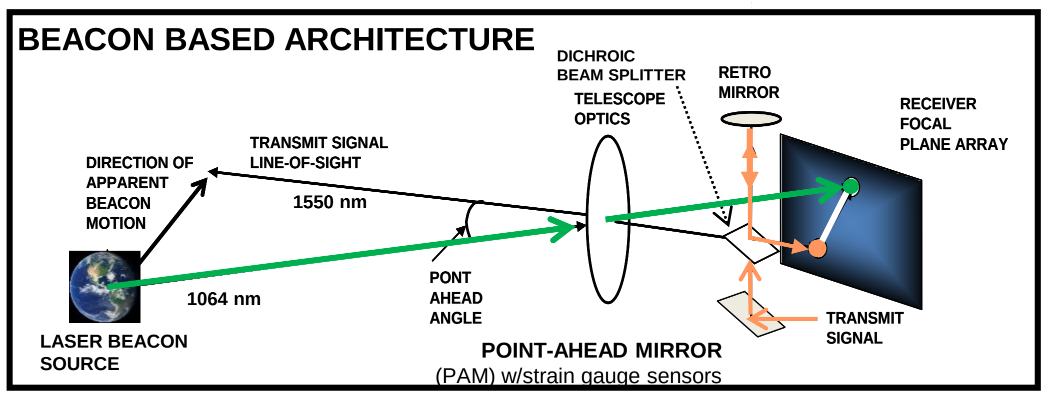


Concept of Operations

- **DSOC tech demo operations concept is under formulation**
  - Following commissioning and calibration a typical day-in-the life will involve: A
    - Transmit ground laser beacon using predicts while Psyche powers FLT and "**coarse poi**nts" to Earth
    - DSOC searches out beacon in s/c pointing uncertainty space
    - FLT stabilizes line-of-sight to Earth with beacon assisted closed-loop control
    - Points downlink to Earth while Ground Receiver is pointing to Psyche using predicts
    - Receive and store downlink
  - Telemetry gathered and stored at FLT for post pass transmission to ground
  - Limited "real time" telemetry during pass may be available



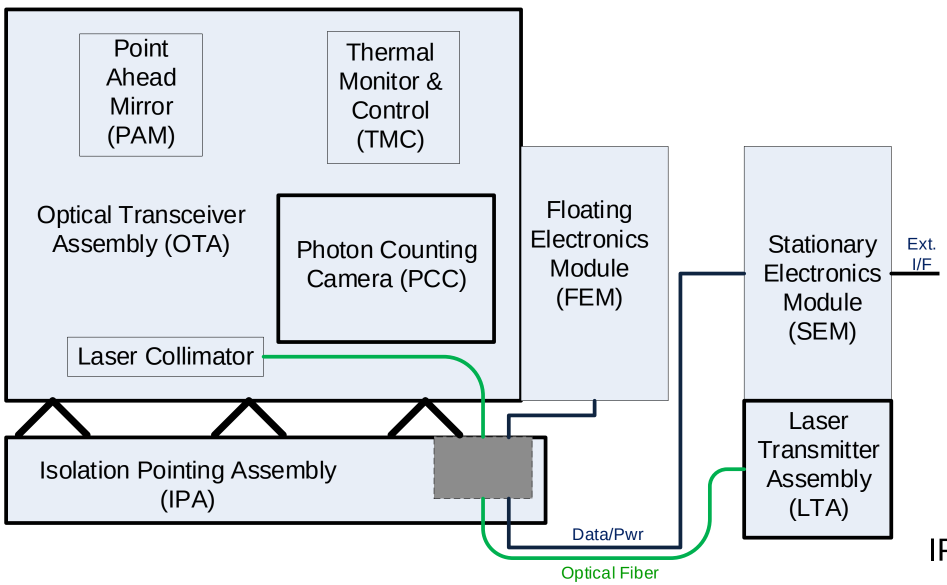


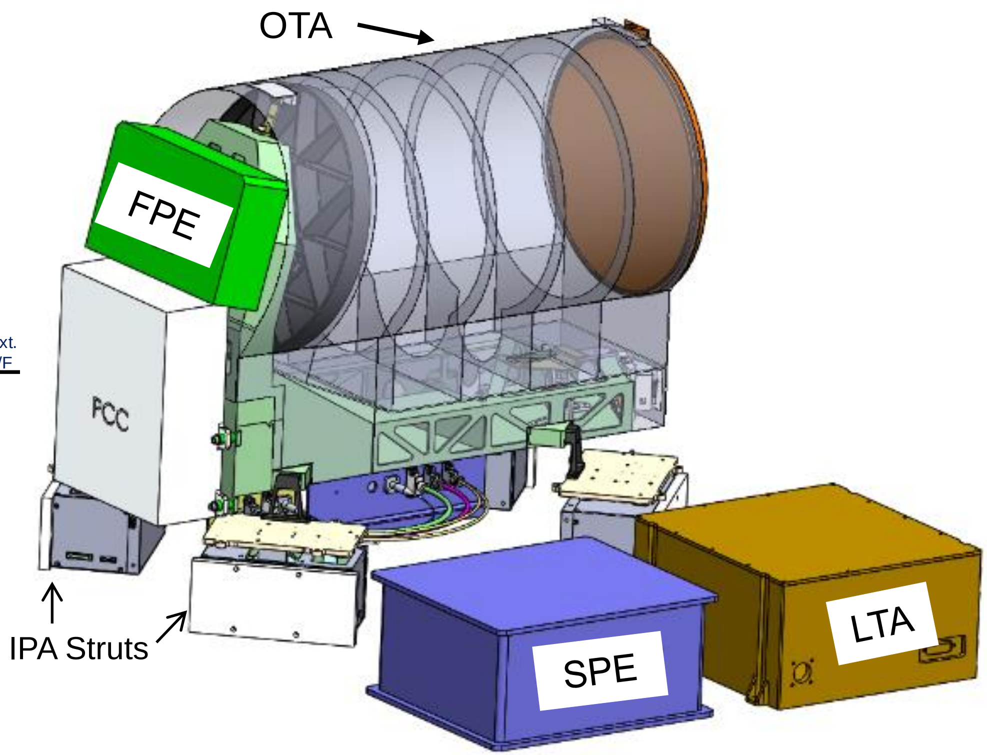


Spot offset is PAA
(For PAA > FOV
- PAM strain gauge tracks PAA
- Strain gauge calibrated with Tx spot

DSOC Flight Laser Transceiver (FLT)

- **The Flight Laser Transceiver (FLT) makes up the flight subsystem**
  - **Silicon carbide (SiC)** Optical Telescope Assembly (OTA) receives beacon and transmits downlink
  - **Photon Counting Camera (PCC)** detects “dim” 1064 nm laser beacon transmitted from Earth
  - **Isolation Pointing Assembly (IPA)** “floats” OTA to stabilize and steer OTA line-of-sight
  - **Laser Transmitter Assembly (LTA)** delivers high peak power pulse train modulated by downlink data
  - **Electronics** – firmware/software platforms, power and clock distribution for “floating” and stationary parts, power and data interface to spacecraft

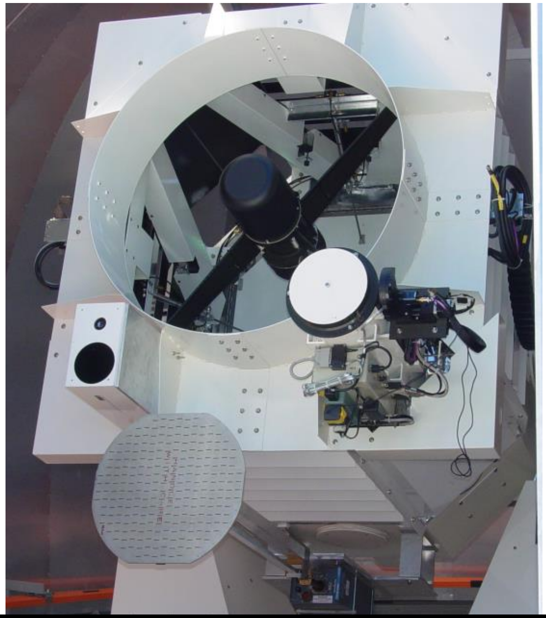




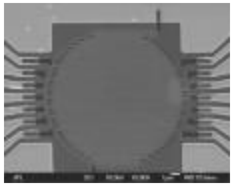
DSOC Ground Data System (GDS)

- **DSOC technology demonstration would utilize**
  - Ground Laser Transmitter at OCTL telescope near Wrightwood, CA
    - Retrofit high power (5 kW) laser transmitter @ 1064 nm
  - Ground Laser Receiver at Hale telescope at Palomar Mountain, CA
    - Tungsten silicide (WSi) superconducting nanowire single-photon detector (SNSPD) array w/signal processing electronics
  - Mission ops center for coordinating ops (not shown)

POSTER 10524-62
on SNSPD Detector Array
(Jason Allmaras)



Optical Communication Telescope Laboratory (OCTL) 1m aperture
Az/El Drive



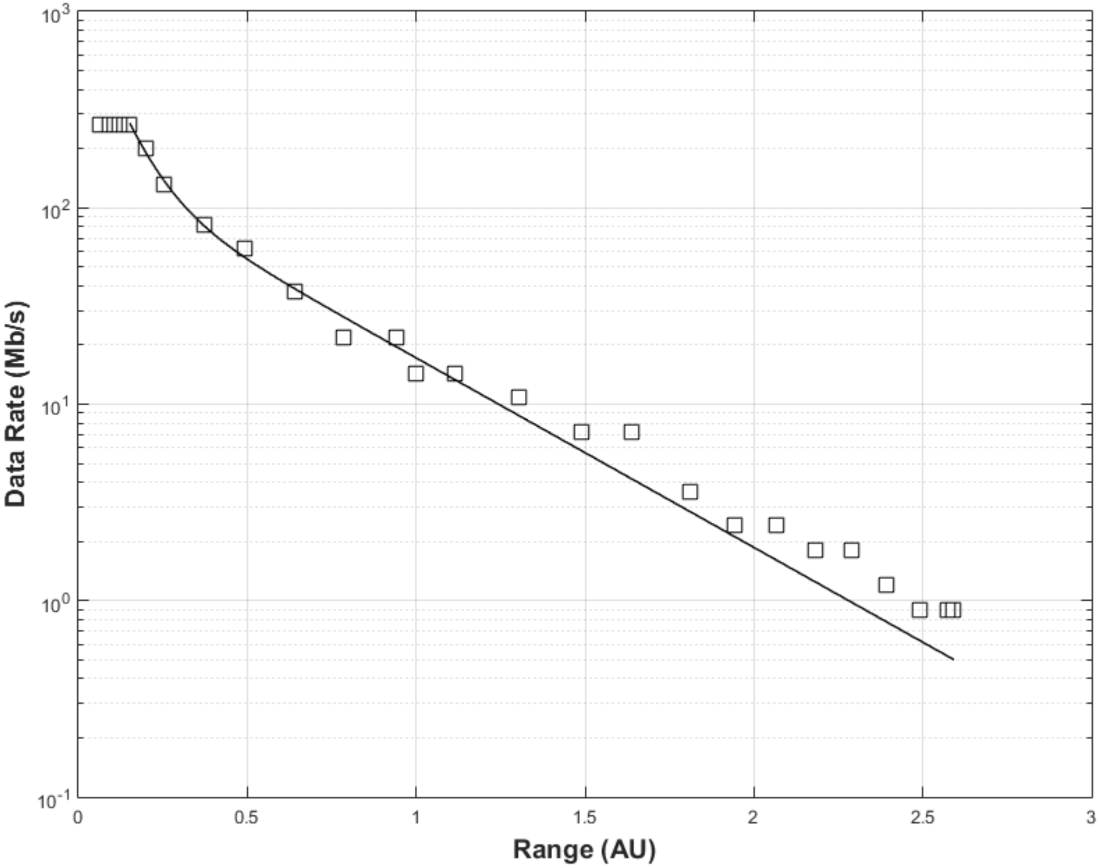
SNSPD array (~ 320 μm dia.)

Ground Laser Receiver(GLR)
– Photon-counting ground detectors
– 50% Eff. WSi nanowire arrays

Predicted Nominal Link Performance

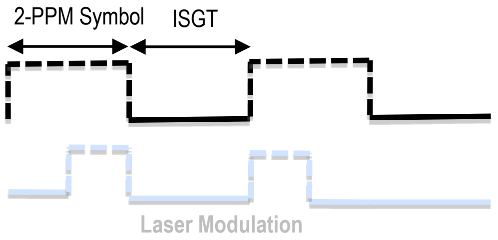
- 4 W average power laser with 22 cm diameter FLT
- Received with 5m diameter Hale Telescope and SNSPD based

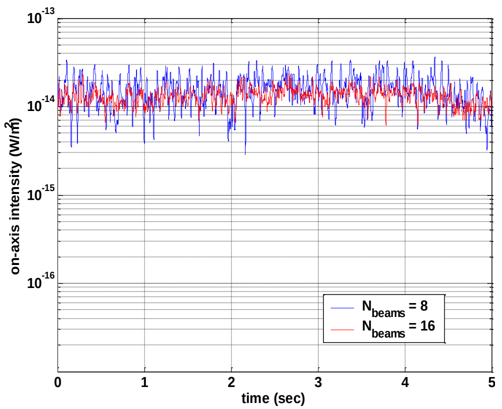
Predicted Nominal Downlink Performance



Uplink

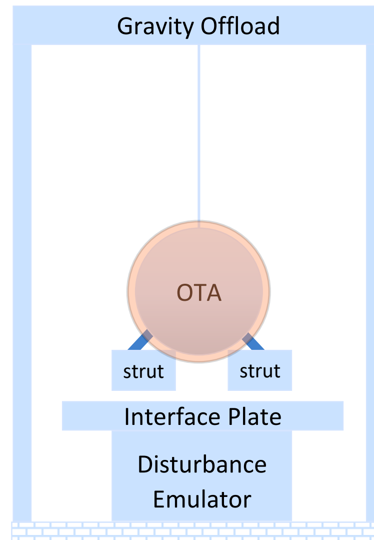
- **1.6 kb/s @ 1 AU**
- **~ 4 pW/m^2 irradiance at FLT aperture**

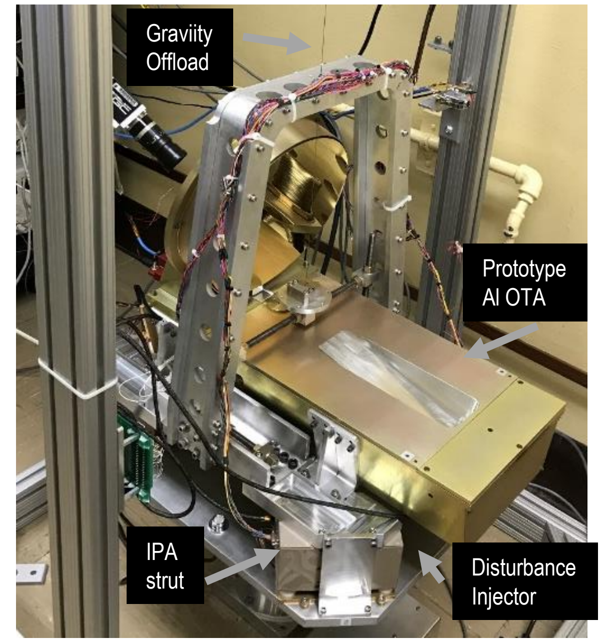


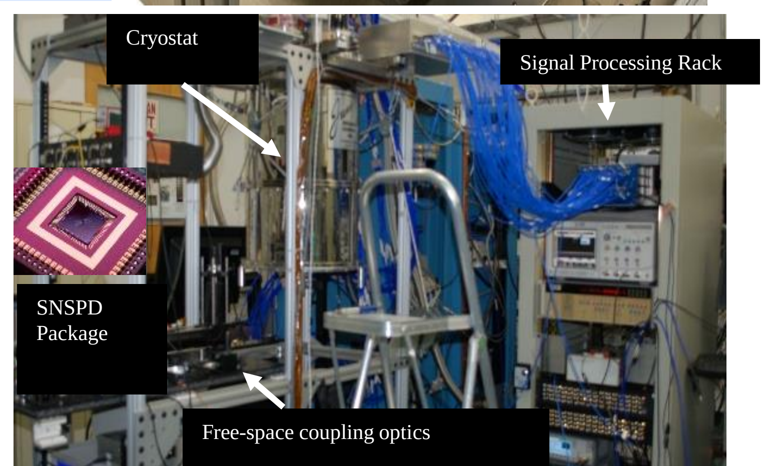


Testbed Activity Summary

- **In preliminary design phase DSOC maintains two end-to-end testbeds**
  - **Pointing and tracking testbed**
    - Gravity off-loaded OTA
    - Integrated to IPA struts
    - Overfilled with 1064 nm beacon
    - Inject base disturbance
    - Tested tracking in presence of disturbance
    - Achieved ~ 1 μrad per axis rms error
  - **Signaling testbed**
    - Generate encoded PPM signal in representative SEM
    - Modulate test fiber laser
    - Free-space couple fiber output to cryostat with SNSPD array
    - Calibrate/Attenuate incident average power to representative signal flux
    - Add background flux
    - Verified operating points including
      - 267 Mb/s, 16-PPM, 0.5 ns slot, 0.66 code rate
    - Adding fading and Doppler shifts pending





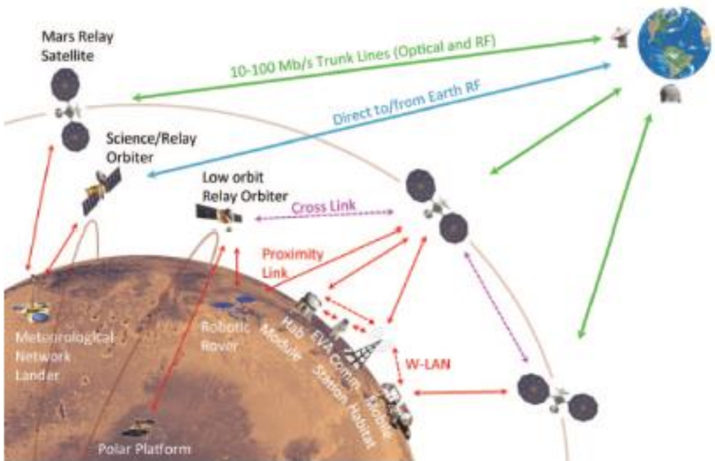


Future Systems

Future Deep-Space Flight Transceivers (FLT)

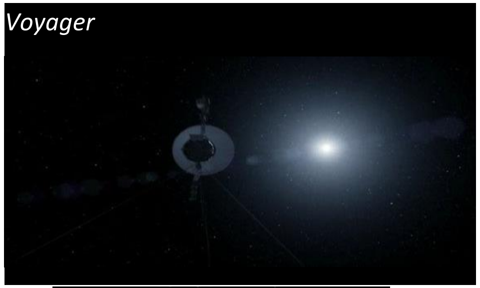
- **Enhanced longer term reliability and scaling of FLT's in post DSOC tech. demo era**

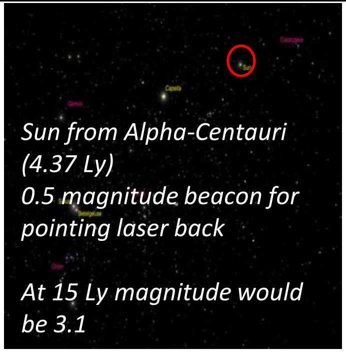
- **Mars telecommunication orbiter would likely be a near-term Infusion of technology validated by DSOC tech demo**
  - Data rates would drive for higher emitted isotropically radiated power (EIRP)
  - Relatively low-risk considered to be
    - 50 cm and 20-50 W
    - Higher effective laser power could be achieved by multiplexing >1 wavelength channel
    - Pointing and thermal challenges of operating pointing close to sun



Robert E. Lock, Charles D. Edwards Jr., Austin K. Nicholas, Ryan Woolley, David J. Bell, "Small Areostationary Telecommunications Orbiter Concepts for Mars in the 2020s," IEEE Aersospace Conference, 1-12, 2016.

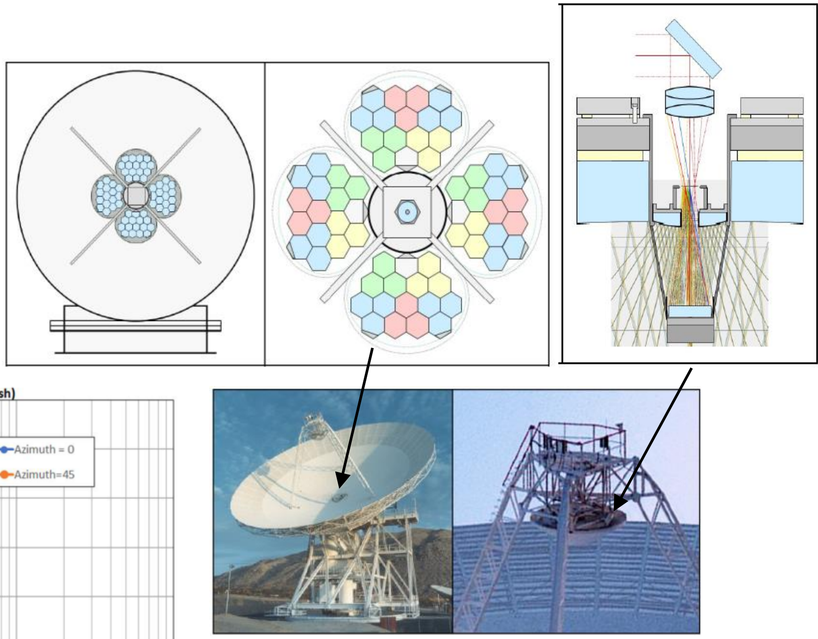
- **Even higher EIRP demands expected for farther missions**
  - For inter-stellar missions (100's of AU) – 50 cm, 100's of W average power
  - Exoplanet missions (5-15 Ly) 2.5 m aperture with 1000's of watt transmitters
  - New challenges
    - Beaconless architecture
    - Pointing, thermal, lifetime (at least 50 years for exoplanet)
    - Light time of 5-15 years???
    - Huge Doppler shifts



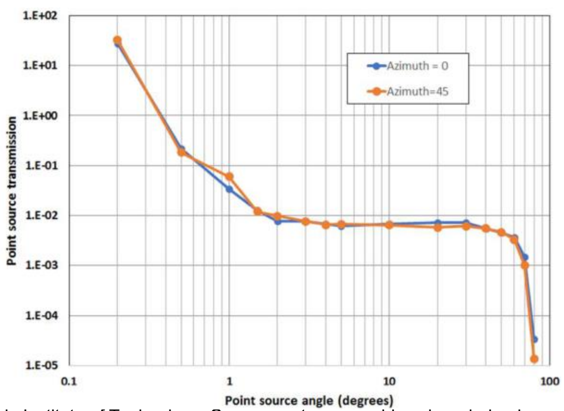


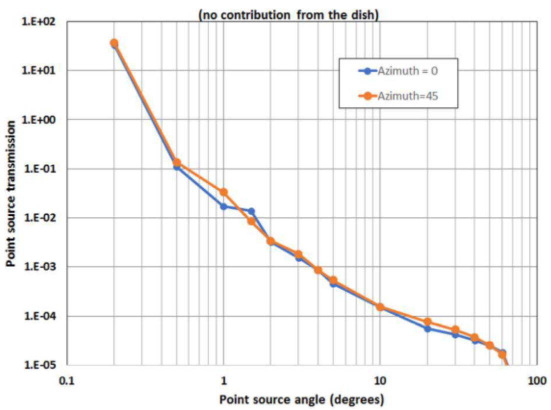
Future Ground Assets

- **Ground infrastructure for deep space optical communications is lacking**
  - Severe impediment to operations even from Mars ranges
  - Astronomical assets not the right answer beyond tech. demos
- **For relatively low investment retrofitting optical surface to existing RF antennae being studied at JPL**
  - ~ 8 m aperture with spherical figure (actively maintained with edge sensors)
  - Recently studies stray light for dome-less concept
  - Stray light analysis
    - Surfaces in vicinity of mirror pods contribute worst stray light
    - Eliminating this surface provides acceptable stray light
  - Possible solution is use of a specially designed Lyot stop
    - 75% reduction in effective aperture from practical implementation constraints
    - Reduced aperture of ~ 6 m at shallow sun-earth-probe (SEP) angles of TBD –to-10 degrees



DSN 34-m antenna





Summary

- **Reported status of DSOC technology demonstration**

- **Pointers to future developments driven by likely near and longer term demands**
- **Near Term**
  - Enhanced longer term reliability flight transceivers
  - Larger EIRP achievable by relatively low-risk scaling for Mars and outer planets
  - Possible low investment RF-Optical Hybrid systems
- **Long term**
  - Orders of magnitude higher EIRP flight transceivers
    - Lasers challenged, lifetime, high power, power and thermal management
  - Earth receiving apertures not addressed